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ERS SAR IMAGERY FOR URBAN CLIMATE STUDIES

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ABSTRACT

This study investigates the potentialities of ERS SAR imagery for the urban micro-climate and air quality, over the city of Nantes, France. The temporal variability of the SAR signal over the city has been assessed by analyzing five images in descending mode. Beside the speckle effect, the quality of the signal is highly variable from one image to the other. Meteorological effects. make contrasts between objects and their surroundings to be more or less pronounced. Urban features are mostly present in each image, but the structures are not always well perceived within a single image. It is concluded that it is necessary to have several images. Their redundancy allows a better exploitation of the urban features. Further it decreases the level of speckle. Screening of the average SAR image clearly indicates that the perception of the roads is highly dependent on the flight direction of the spacecraft. The main factors for the perception of the morphological features are the height of the buildings, its orientation relative to the spacecraft orbit, its horizontal surface, its materials. Multiresolution analysis, by means of wavelet transform or structure function, provides a good discrimination between unbuilt areas, residential areas, industrial areas, and large groups of buildings. This preliminary study has demonstrated that urban morphological features and their typologies with relation to the air flow drag were well-perceived in SAR imagery once properly processed. Further studies are required to assess definitely the benefits and the limits of such images in urban micro-climate and air quality.

Keywords: SAR imagery, urban micro-climate, air quality, roughness

1. INTRODUCTION

The city's compact mass of buildings and pavement constitutes a profound alteration of the natural landscape, resulting in a large number of micro-climates (Carnahan, Larson, 1990; Landsberg, 1981; Oke, 1987; Terjung, O'Rourke, 1980). These micro-climates may be revealed by the existence of the so-called *urban heat islands* where changes in the temperature of the atmosphere may reach several degrees compared to that of the neighbor rural area. The complex and changing mosaic of heat and cold islands influences urban ecology in a variety of ways by altering e.g., the health and physiological comfort of humans, cooling and heating requirements, vegetation, and zoological habitats. The heat islands also produce convection cells and associated air pollution diffusion patterns with increases in cloud coverage, precipitation and fog. Various scales should be taken into account in studies of urban climate, from several hundred of kilometers to the very small scales at the pedestrian level (Landsberg, 1981; Oke, 1987; Price, 1979).

The present investigation aims at the assessment of the potentialities of ERS SAR imagery for the urban micro-climate and air quality, namely urban morphological features and their typologies with relation to the air flow drag. The selected site is the city of Nantes, along the Loire River, west of France.

The investigation has three consecutive steps. The time variability of the SAR signal is analyzed in order to check whether several images may provide an useful information over a city. That demonstrates the relevance of the SAR signal for the study of urban features. Then the mean image is visually inspected with respect to a map of the city. It clearly shows the main features, that proves the significance of the SAR signal in this purpose. Finally, a mathematical method is devised for the automatic discrimination of the districts with respect to the aerodynamic roughness of the ground.

2. ACQUIRED IMAGE AND PRE-PROCESSING

Five SAR images were provided by ESA, from October 1994 to April 1995. Radial direction is almost East - West. The images were geometrically modified as follows. Six consecutive pixels belonging to the same column were averaged and replaced by their average. This reduces the number of lines and results into an approximately squared pixel of 25 m. The best image was geometrically rectified in order to fit a map with a scale of 1/100 000 in Lambert III projection by means of a bicubic interpolation, and the result constitutes the reference image. The other images were rectified with respect to this reference. The speckle was not filtered out in each image. Several tools are available which are respectful of the most pronounced structures. However we have preferred not to alter the structures any further after the geometrical rectification.

The morphological features of interest are constant within the time span of our data set. The first step in our analysis is to assess the temporal variability of the SAR signal over the city. All images have been taken in descending mode, thus reducing the influence of the acquisition geometry. The whole set of images has been inspected visually and the mean image as well as the differences between the mean and each image have been constructed from the five superimposable images. The mean image is taken as the first component computed from a principal component analysis. This component comprises about 80 % of the total variance.

It has been found that beside the speckle effect, the quality of the signal was highly variable from one image to another. The discrepancies in the observation of the major elements of the scene were mostly explained by meteorological effects. According to the wind vector (speed and direction), contrasts between the river and its surroundings may be more or less pronounced, due to changes in wave regime. Hence the wind has a strong influence on the detection of bridges and of natural or artificial banks. It has been found that the direction has a greater effect than the speed of the wind. Rainfall has also an effect upon the quality of the image. The dielectric constant is a function of the soil humidity: therefore contrasts between natural or vegetation areas and built areas depend also upon the quantity of rain fallen in the time period before the acquisition date.

Urban features are present in each image. Each image provides a good overall description of the structures. However because of the changing quality, the structures are not always well perceived within a single image. We conclude that it is necessary to have several images. Their redundancy allows a better exploitation of the urban features. Further their averaging decreases the level of speckle without using sophisticated speckle filters which usually degrade the structures.

3. INTERPRETATION OF THE MEAN IMAGE

Figure 2 displays the mean image. The visual inspection demonstrates the importance of the relative direction of the target with respect to the radial direction of the radar wave. If the relative direction is perpendicular to the radial direction, then this object is clearly visible, even if it is flat such as a road or a railway track within a flat area. If the object is orientated in the same direction than the radar wave, then it is not visible. This is the case for the central station of Nantes and of the large railway complex in the western part of the Beaulieu island. However if the same object is surrounded by e.g., buildings reflecting the radar signal, it will be perceived because of the created contrast.

The material of the objects is also important. For example, the group Malakoff is made of several large buildings of about 20 stores each. This group does not appear in the image because the buildings are covered of ceramics which do not reflect the radar signal.

Regarding the main urban features, we conclude that

- the industrial buildings are well perceived and bright (*i.e.* highly reflective),
- the large buildings are well perceived,
- the areas comprising old buildings with more than one store are well perceived if they are mostly orientated perpendicular to the direction of propagation of the radar wave,
- the residential areas are homogeneous and low reflecting
- the unbuilt areas are low reflecting

The morphological features are likely related to the aerodynamic roughness parameters of the ground which influence the air turbulent flow. These parameters are the roughness length (noted z_0) and the zero-plane displacement. They are useful to describe and quantify the turbulent way the air flows above the ground and the structure, the reduction in wind speed and accordingly in the air turbulent mixing. They depend upon the nature of the ground and of its geometry, e.g. the buildings, their shape, their height, their spacing, their orientation with respect to the air flow, É. The main factors for the perception of these morphological features are

- the height of the buildings (mean and variance),
- their orientation relative to the spacecraft orbit,
- their surface onto the ground,
- their materials

5. CLASSIFICATION OF DISTRICTS WITH RESPECT TO AERODYNAMIC ROUGHNESS

Scherer *et al.* (1996) have conducted a study for the classification of the city of Basel (Switzerland) with respect to aerodynamic roughness parameters. They computed the principal components of a set of three ERS SAR images. Then they performed a multiple linear regression analysis between the first two components and z_0 values taken from the literature. They concluded that SAR images may be used to map the roughness length in the city of Basel. Obviously the found relationship strongly depends upon the SAR images used for this study and maybe of the site. This prevents the relationship to be used elsewhere or with other images. In order to alleviate this shortcoming, the present study investigates some mathematical operators which are a bi-dimensional function of the urban structures, which provide a good discrimination of the districts with respect to the aerodynamic roughness parameters, and which can be normalized in order to render them invariant with respect to the set of images and of the site, possibly. Then, following the work of Scherer *et al.*, a relationship may be devised by a multiple linear regression analysis, using z_0 values taken from the literature. Finally the SAR-derived image may be classified in terms of roughness length.

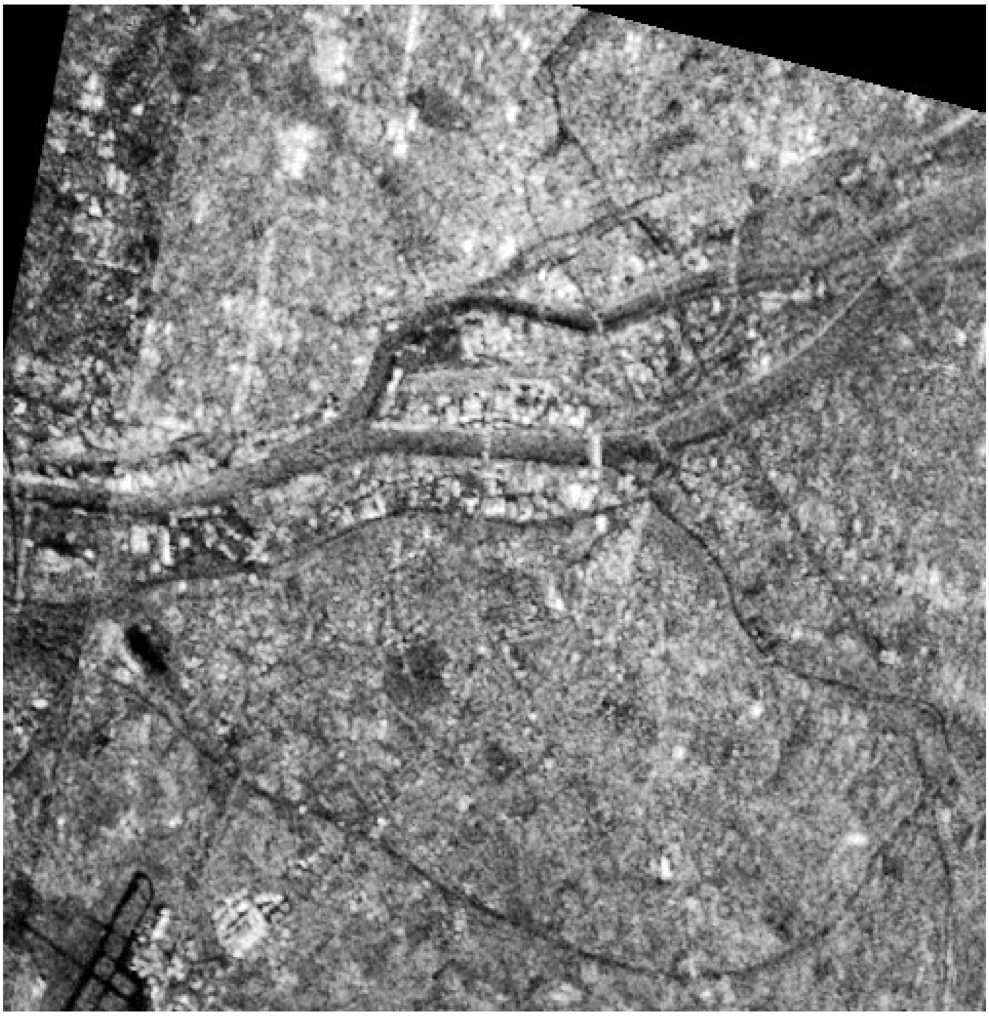

Figure 1.
Mean image computed from the five SAR images. The Loire river appears in grey, crossed by several bridges in bright. In dark are the major roads, and the airport in the lower left corner. The island is the island of Beaulieu, and is part of the city of Nantes. The area is mostly comprised of urban areas, but also of some agricultural lots and woods, which are not distinguished each from the other in this image.

Obviously the roughness is a function of the scale of concern. Therefore tools for multiresolution analysis have been applied onto the mean image to extract the relevant information at various scales. Two operators have been found to be the most efficient with respect to their quality in discrimination and their easiness in use and analysis: the multiresolution analysis, coupled with a wavelet transform, and the structure function, also called variogram. It is found that the multiresolution analysis is well suited to distinguish groups of buildings, with typical scale of about 100 m. This approach provides also a good discrimination between unbuilt areas, residential areas, industrial areas, and large groups of buildings. Structure functions give very similar results. Their degree of anisotropy is a function of the density and type of buildings, and of the overall orientation of the area. It depends upon the scale. Another parameter is the variance of the sample, which is given by the value for the largest scale. The closer to the pixel size the typical size of the objects and the more homogeneous the district, the smaller the variance. Privileged directions within a district and heterogeneous district increase the variance. The last parameter of importance is the value of the structure function for the scale equal to one pixel (the nugget effect). This value is comprised of the non structured noise within the image (*i.e.* the speckle), which has been reduced by the averaging of the five images, and of the sub-pixel variance, that is of the heterogeneities having a scale smaller than, but close to, the pixel size. The more heterogeneous a district at sub-pixel size, the larger the nugget effect.

For example, Figure 2 exhibits the structure function for a district made of spaced large buildings (West Beaulieu island). In this district, the storage buildings are located along the docks, with metallic parts, and components perpendicular to the radial direction. These components are clearly visible in the SAR signal while the radial components are not or less sensed. This induces a larger signal in the E-W direction than in the N-S one, which creates an anisotropy in the structure function for sizes larger than about 70 m. The structure function exhibits a finite variance for the largest pixel sizes. This means that the size of the sample (here 7 pixels, that is about 200 m) is larger than the typical size of the structures in this district. It follows that the structure function is a suitable tool to discriminate types of buildings and their organization with respect to the aerodynamic roughness parameters.

5. CONCLUSIONS

This study has shown that the main morphological features within a city are mostly present within a SAR image. However, the quality of the signal is highly variable from one image to the other. The discrepancies in the observation of the major elements of the scene were mostly explained by meteorological effects. Because of this change in quality, the structures are not always well perceived within a single image. It is concluded that it is necessary to have several images. Their redundancy allows a better exploitation of the urban features. Further their averaging decreases the level of speckle. The screening of the average SAR image clearly indicates that the perception of the roads is highly dependent on the flight direction of the spacecraft. The morphological features are likely related to the ground roughness. The main factors for the perception of these morphological features are the height of the buildings (mean and variance), its orientation relative to the spacecraft orbit, its surface onto the ground, its materials. Relevant processing has been performed to the mean image to extract the relevant information at various scales. Multiresolution analysis, by means of wavelet transform or structure function, provides a good discrimination between unbuilt areas, residential areas, industrial areas, and large groups of buildings.

Given the importance of the orientation of the target relative to the spacecraft orbit, further investigations should be made using images taken at various orientations. Image processing techniques are to be further developed and carefully assessed for an automatic detection and classification of morphological features. Campaigns of ground-measurements are necessary to establish quantitative relationships between the properties of these morphological features as observed in the SAR imagery and the roughness length.

This preliminary study has demonstrated that urban morphological features and their typologies with relation to the air flow drag were well-perceived in SAR imagery once properly processed. It is concluded that SAR images have large potentialities in the domain of urban micro-climate and air quality and that further studies are required to assess definitely the benefits and the limits of such images.

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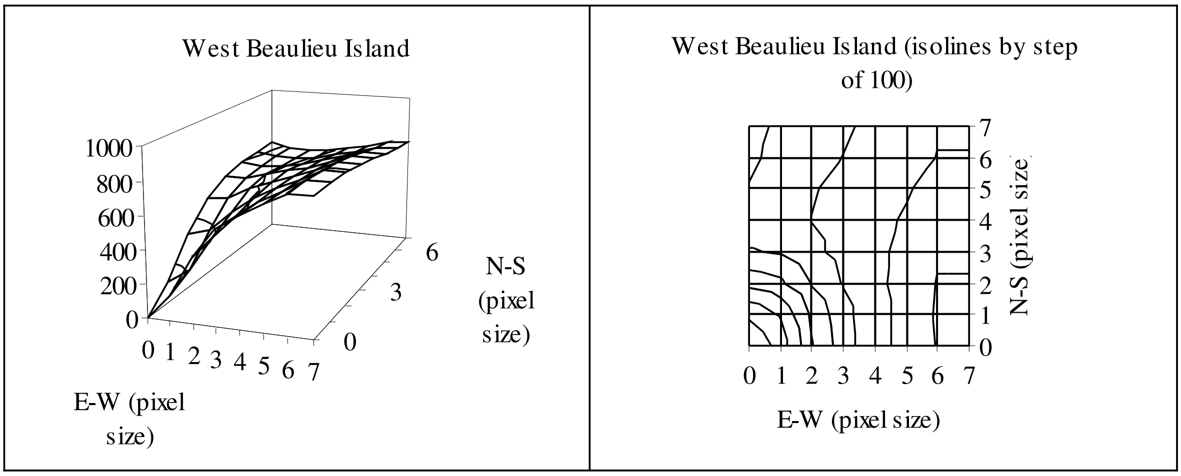

Figure 2 Structure function for a district made of spaced large buildings. The left graph (3.a) shows the structure function in 3-D, the right graph (3.b) shows its projection (in isoline) onto the x-y plane. Pixel size is 25 m.